Transport Behavior and Conversion Efficiency in Pillar Structured Neutron Detectors

Rebecca J. Nikolić
(925) 423-7389
nikolic1@llnl.gov

Room temperature, high efficiency and scalable radiation detectors can be realized by manipulating materials at the microscale. With micro-semiconductor-pillars, a thermal neutron detector with an efficiency of over 70% is possible. New material science, new transport behavior, neutron-to-alpha conversion dynamics and their relationship with neutron detection will be discovered with the proposed structures.

Project Goals

Our goals for FY2007 include:
1) neutron-to-alpha conversion efficiency in high resistivity CVD ^{10}B films and understanding of impurities;
2) thermal neutron detector demonstration with 20+ µm pillar height;
3) electron and hole transport in vertical high-aspect-ratio structures; and
4) model of pillar detector that includes both nuclear physics and semiconductor device physics.

Relevance to LLNL Mission

Radiation detection requires both neutron and gamma detectors that are inexpensive, operable at ambient temperature, high efficiency and robust. Currently available detectors typically fall short in at least one of these areas.

^{3}He neutron detectors are currently used for typical neutron detection. However, they have major fieldability issues, such as microphotonic interference, high voltage, and large device footprint. Also, the ^{3}He gas makes air transport difficult. New materials and device structures are needed for revolutionary improvement in radiation detectors. By applying microtechnology methods to the area of neutron detection, we will be able to make revolutionary improvements in the device efficiency and fieldability.

The proposed solution has a large potential payoff in the area of national security. If all of the requirements in our proposed device can be met, these detectors would be manufactured by partnering with an industrial collaborator and readily deployed to many agencies.

FY2007 Accomplishments and Results

A schematic diagram of the detector is shown in Fig. 1. The platform consists of a P-I-N layer structure grown epitaxially on an n+ silicon (Si) substrate. The epitaxial Si is dry-etched utilizing high-density plasma to form the pillars structure. The converter material (^{10}B) is deposited on the sample in the space between the pillars by chemical vapor deposition (CVD) (Fig. 2).

In FY2007 we have achieved a fill factor of 95+ % for pillar diameter of 2 µm, pitch of 4 µm, and height of 12 µm with ^{10}B. By using this inter-digitated device structure, charged particles (alpha and ^{7}Li) from the thermal neutron - ^{10}B reaction have a higher probability of impinging on the Si P-I-N structures, where electrons and holes are created, which results in high efficiency.

The pillar detector roadmap was further developed in FY2007 using Monte Carlo N Particle (MCNP) transport code to simulate a near-by neutron point source interaction with the structure, after which the range of the charged particles was calculated using Ion-Range-In-MAtter (IRMA) code (Fig. 3).

Further refinement of the pillar detector model was carried out by determining the energy loss within the semiconductor pillar. Silvaco's Atlas was then used to calculate the transport of the electrons and holes generated by the alpha and ^{7}Li

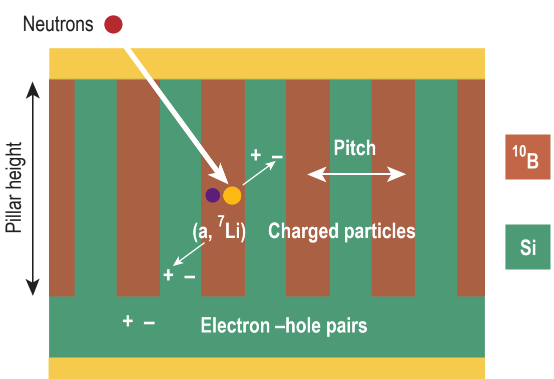

Figure 1. Schematic diagram of pillar detector design.

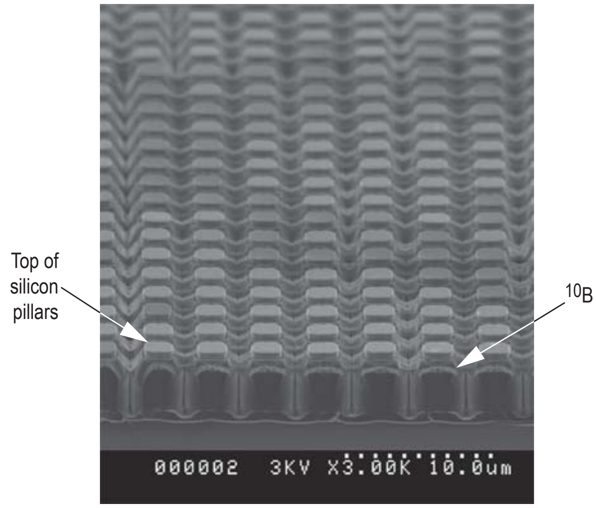

Figure 2. SEM of pillar platform filled with CVD ^{10}B.

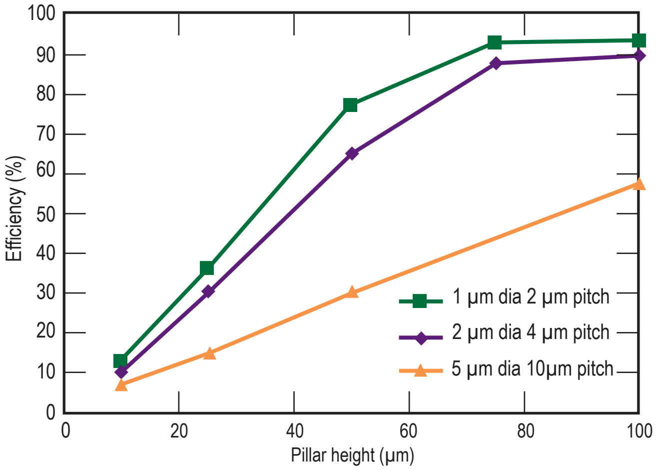

Figure 3. MCNP and IRMA simulations of thermal neutron capture efficiency versus pillar height for several pillar diameters and pitches.

particles in the Si diode portion of the detector at sampled particle energies and heights within the pillar. The collected charge was then calculated by scaling the energy deposited by the ionized particles in the Si pillars by the percentage of carriers that recombine before reaching the contacts, as determined from Atlas charge transport simulations. The pillar geometry simulated in this work had a height of 20 µm, diameter of 2 µm and a pitch of 4 µm. The resulting energy spectrum for the pillar detector is shown in Fig. 4, for 4 million neutron histories and a minimum energy threshold for detection of 100 keV. For the geometry used the efficiency simulated is 18%. This is compared to the 24 % efficiency simulated for the same structure without including the energy loss within the silicon pillars.

Neutron measurements were performed using a 12-µm pillar detector filled with the ^{10}B converter material, as shown in Fig. 5. A ^{252}Cf neutron source with neutron flux of 2.3 x 10^6 n/s was embedded in 15-cm-thick polyethylene blocks for the measurement. The measurement time was 20 h. To obtain the thermal neutron efficiency, the observed events were compared with results from a Monte Carlo simulation. The thermal neutron detection efficiency is estimated to be 7.3 % with an error of 1.4 %.

Related References

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FY2008 Proposed Work

In FY2008 we will pursue: 1) fabrication of *Pillar Detector* (20 µm pillar); 2) ^{10}B coatings of high-aspect-ratio structures and understanding of stress origin and mechanics; 3) electrical, alpha, and neutron measurements of *Pillar Detector;* and 4) the addition of recombination to *Pillar Detector* model.

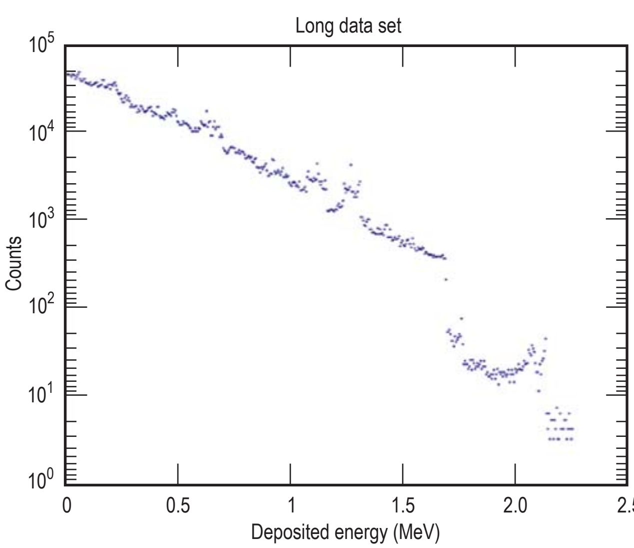

Figure 4. Simulated total energy spectrum (alpha + ^{7}Li) for neutron interaction with 20-µm-tall pillars with 2-µm diameter and 4-µm pitch.

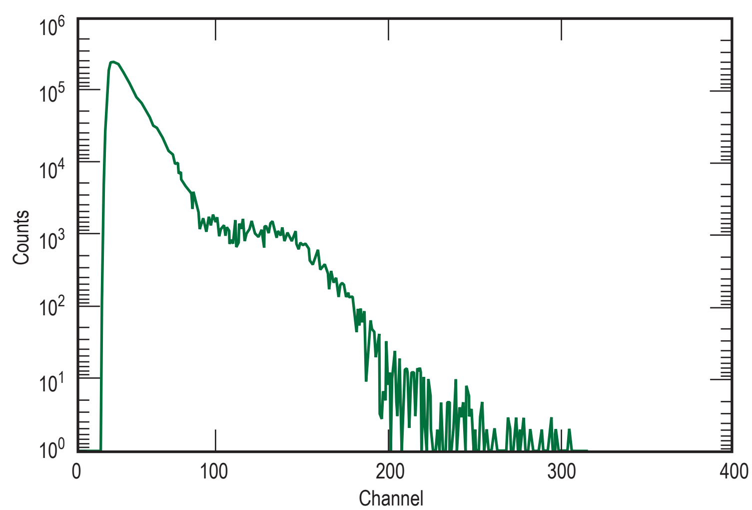

Figure 5. Energy response of a ^{10}B filled 12-µm-tall pillar detector from neutron interaction with ^{10}B.